Population estimation of the Green and golden bell frog *Litoria aurea* at Port Kembla

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ABSTRACT

Estimates of population size are fundamental to the development of effective management of threatened species. We conducted a tagging study of a population of the endangered Green and Golden Bell Frog *Litoria aurea* at Port Kembla, on the New South Wales south coast. Over 200 adult frogs were tagged across three breeding sites between November 1998 and January 2000. Population estimation based on the mark and recapture of frogs in 1999-00 suggested that the two larger breeding sites together contain >300 adult frogs. Although these sites were only 500 m apart, no tagged frogs were recorded to move between them. In contrast, one female bell frog moved 1.25 km between one of these and the third site over a 14 month-period. The ratio of male to female frogs was 2.5:1, suggesting either that the population is male-dominated or that females are more cryptic in their behaviour than males and use habitat differently. Based on this ratio the sites contained at least 85 adult females in 1999-2000. Only 13 frogs were recaptured outside the season of initial capture. The longest interval between captures was 14-16 months, for three of these frogs. This suggests that few frogs live longer than about 2 years as adults. Given that a small number of other breeding sites occur in Port Kembla, the total population size is estimated to exceed 400 adult frogs. Further study of this important population is needed to refine these estimates of population size and to confirm population stability.

Key words: bell frog, *Litoria aurea,* endangered frog, population estimation

Introduction

The green and golden bell frog *Litoria aurea* is a large tree frog that has undergone a well-documented contraction in its geographic range and decline in abundance (Osborne *et al.* 1996; White and Pyke 1996). It is presently listed as endangered in New South Wales (NSW) under the NSW *Threatened Species Conservation Act* 1995 and vulnerable by the Australian Commonwealth under the *Environmental Protection & Biodiversity Conservation Act* 1999. Many studies have now been conducted on numerous aspects of its ecology (see Pyke and White 2001). However, critical to formulating appropriate recovery actions will be gaining an adequate understanding of its population ecology at sites throughout it geographic range (Goldingay 1996). One of the key population parameters required to guide recovery actions is an estimate of population size based on appropriate survey effort. Currently, there are few published population estimates for this species. White and Pyke (1996) provided preliminary population counts for most sites in NSW. These data were derived from numerous field workers using various methods and sampling intensities, and largely represent single census maximum counts. More recent but detailed survey work suggests there may be seven populations in NSW that contain about 1000 adult frogs (Pyke and White 2001).

Populations of the green and golden bell frog occur in the Illawarra region of NSW, south of Sydney. The most significant population in this region is one centred on Port Kembla. Preliminary monitoring of this population suggested that it contained 100-150 adult frogs (Goldingay and Lewis 1999). The most important breeding site at this location is Coomaditchy Lagoon. This site is also of considerable importance for gaining a better understanding of the conservation requirements of this species because it is one of the few in NSW where bell frogs successfully breed in the presence of a high density of predatory mosquito fish *Gambusia holbrooki* (van de Mortel and Goldingay 1998; Goldingay and Lewis 1999). Although there has been population monitoring of bell frogs conducted at Coomaditchy Lagoon, a study that employs tagging is needed to provide a more precise assessment of the size of the bell frog population (Goldingay and Lewis 1999).

The aim of this study was to conduct a mark-recapture study of bell frogs to estimate the number of adult frogs at Coomaditchy Lagoon and some nearby breeding sites, and to document the frequency of movements of frogs among these sites.

Methods

Study area

Detailed field work was conducted at three sites in Port Kembla: Coomaditchy Lagoon, South Pond and Boilers Point pond (Fig. 1; see also Goldingay and Lewis 1999 for details). Coomaditchy Lagoon is a large natural

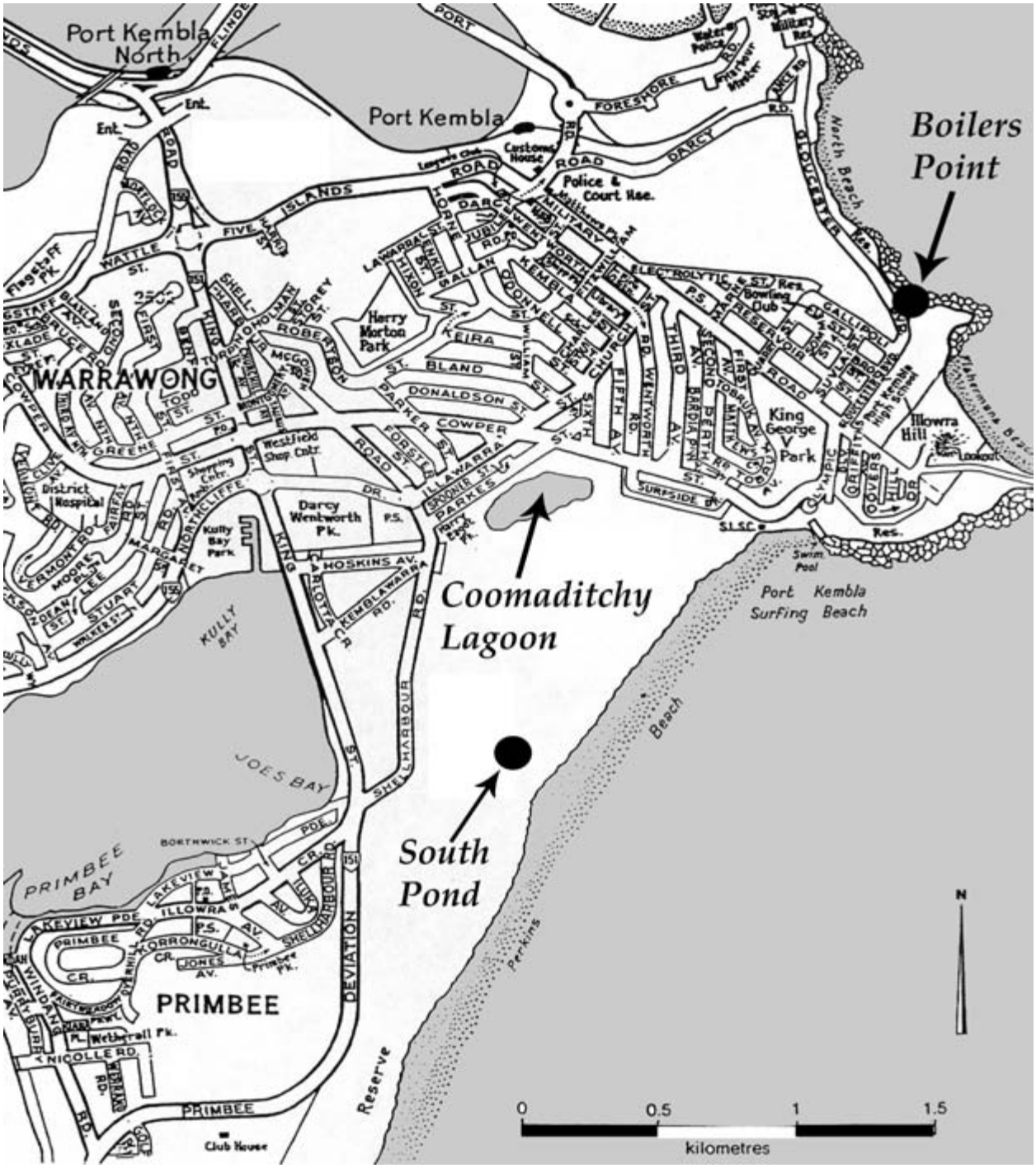

Figure 1. Locations of three breeding sites at Port Kembla.

lagoon, measuring about 2 ha in area. It is surrounded by residential development and roads on three sides, and buffered by a 50-100 m wide area of mown lawn (Figs 2, 3). On its south-eastern side there are vegetated sand dunes. South Pond (Fig. 4) is located 500 m immediately south of Coomaditchy Lagoon. The area between the two sites consisted of highly disturbed vegetated sand dunes that were regularly used for riding of trail bikes. The pond at Boilers Point (Fig 5) was constructed in 1997, partly to offset the loss of breeding habitat 200 m to the north of it. This site is located 1.2 km north-east of Coomaditchy Lagoon. The habitat present at these sites has been described previously (van de Mortel and Goldingay 1998; Goldingay and Lewis 1999).

Frog surveys

Surveys were conducted between November 1997 and February 2001. This consisted of 3-7 nights of field work in October-December and 1-3 nights in January-February in each year. For individual sites, this effort varied with most expended at Coomaditchy Lagoon (Table 1) due to its bigger size compared to the other two sites. Previous extensive field work in Port Kembla had established the optimal periods for conducting these surveys (see van de Mortel and Goldingay 1998; Goldingay and Lewis 1999). Although prevailing weather can affect the presence of frogs at breeding sites (van de Mortel and Goldingay 1998), frogs were readily detected (Fig. 6) and usually called spontaneously during

Figure 3. North-west edge of Coomaditchy Lagoon showing beds of tall spikerush *Eleocharis spaceolata.* Photo: R. Goldingay

Figure 3. North-west edge of Coomaditchy Lagoon showing beds of tall spikerush *Eleocharis spaceolata.* Photo: R. Goldingay

Figure 4. South pond in the sand dunes behind Port Kembla beach. Photo: R. Goldingay

Figure 5. The constructed pond at Boilers Point, Gloucester Boulevard. Photo: R. Goldingay

Table 1. Number of adult frogs captured at Port Kembla sites. Recaptures are frogs previously tagged. Period refers to year period.

Date	No. survey nights	Females	Males	Total	Recaptures Same period		Recaptures Different period	
1997-98					**F**	**M**	**F**	**M**
Coomaditchy	5	7	7	14	2	1	-	-
South Pond	0	-	-	-	-	-	-	-
Boilers Pt	4	1	6	7	0	6	-	-
1998-99								
Coomaditchy	7	11	25	36	1	14	0	0
South Pond	3	3	12	15	0	0	-	-
Boilers Pt	3	3	20	23	0	2	0	0
1999-00								
Coomaditchy	7	21	37	58	3	6	1	7
South Pond	4	16	53	69	3	11	1	2
Boilers Pt	4	2	8	10	0	0	0	0
2000-01								
Coomaditchy	4	5	7	12	0	1	2	0
South Pond	0	-	-	-	-	-	-	-
Boilers Pt	0	-	-	-	-	-	-	-
Total		**69**	**175**	**244**	**9**	**41**	**4**	**9**

Figure 6. Bell frog resting amongst cumbungi. Photo: R. Goldingay

Figure 7. Bell frog resting amongst jointed rush *Juncus articulatus*. Photo: R. Goldingay

spring at Coomaditchy Lagoon. Surveys at South Pond commenced in November 1998 when it was first located. We searched the entire periphery of each breeding site on foot with a 50 W spotlight during nocturnal surveys. This included searching the water's edge as well as any fringing vegetation within 5 m (Fig. 7). We followed the NSW frog hygiene protocol (NPWS 2000).

Bell frogs were captured and placed in plastic bags. They were sexed (based on the presence of nuptial pads), their snout-urostyle (SU) length was measured and they were weighed. Frogs measuring at least 50 mm in length were classed as adults. A description was made of the dorsal markings of each frog (excluding head), describing the relative coverage and locations of brown and green markings. This was conducted initially to aid individual identification but was used to broadly characterise the pattern of colour variation in the population for comparison with other populations such as in northern NSW where bell frogs are predominantly brown (see Goldingay and Newell 2005). Captured frogs were placed into one of four categories: uniform green; predominantly green with minor amounts of brown dots, lines and blotches; predominantly green with major amounts of brown blotches; and uniform brown. A uniquely-coded Passive Integrated Transponder (PIT) tag was injected subcutaneously into the left side of each newly captured frog using a method similar to Christy (1996). The tag was manipulated to position it near the groin and away from the site of insertion, which was sealed with Vetbond (3M). The insertion point in the skin healed within several days of tagging. Each captured frog was scanned with a microchip reader to determine its identity and whether it had been tagged previously. The frog was later released near the point of capture.

The SU lengths of frogs captured in different months in 1999/00 were compared. Samples were pooled for Coomaditchy Lagoon and South Pond using captures in October, November and January. Differences could indicate either that frogs were growing larger during the season or that different cohorts of frogs dominated (or became more active) during different months of the breeding season.

Two different methods were used to estimate the size of the local bell frog population at two of the sites. Sufficient data were collected at Coomaditchy Lagoon for analysis in October and November 1999, and January 2000. Sufficient data were collected at South Pond in October and November 1999. During other periods, none or only small numbers of frogs were detected. Where three capture periods occurred with adequate data, the Schnabel method was used; the Peterson method was used when there were only two capture periods with adequate data (Krebs 1989). The most important assumptions of these methods are that a population is closed during the interval used and that animals have an equal chance of being captured (Krebs 1989). The first assumption is likely to have been true when using data for periods within a given active season (September-March), though the extent of any migration among breeding sites is unknown. The second assumption may not be true so any estimate should be treated with caution.

Results

The number of frogs captured varied at each of the sites over the study period. Only 22 frogs were captured at Coomaditchy Lagoon and Boilers Point during seven nights between November 1997 and January 1998 (Table 1). In contrast, there were 74 frogs captured across the three sites during eight nights between November 1998 and February 1999. There were 137 frogs captured across the three sites during eight nights between October 1999 and January 2000. Only 12 frogs were captured during four nights between October 2000 and January 2001. South Pond was surveyed over only two breeding seasons, in which time 84 frogs were captured. In comparison, 94 frogs were captured at Coomaditchy Lagoon, which is a much larger site and always has permanent water.

Over the course of the study, 121 individual frogs were captured at Coomaditchy Lagoon, 84 at South Pond and 40 at Boilers Point. The overall sex ratio was one female to 2.5 males. Of the frogs captured, 46 were

recaptured within the season of initial capture (Table 1). There were 13 frogs captured the season after they were tagged, including six that were recaptured within the season of tagging. Of those recaptured in a subsequent season, a larger proportion were females compared to those recaptured within the season of being tagged. Only a single movement among the three breeding sites was detected. A female frog first captured at Boilers Point on 21 November 1999 was recaptured at Coomaditchy Lagoon on 7 February 2001.

The Peterson estimate of the size of the bell frog population at South Pond between October and November 1999 when 69 frogs were captured was 192 bell frogs (95% confidence interval, 103 to 358). The Schnabel estimate of the size of the bell frog population at Coomaditchy Lagoon between October 1999 and January 2000 when 58 frogs were captured was 151 bell frogs (95% confidence interval, 81 to 305). Thus, the total population size across the two sites is likely to exceed 300 adults, and may have exceeded 600 adults.

Morphology

Of 200 adult frogs scored for dorsal colouration, 11% were uniform green, 74% were green with minor brown markings, 15% were green with major brown markings, and none were uniform brown. Male frogs averaged 62.8 mm ± 0.4 s.e. (n=183, range 51-76 mm) in SU length and weighed 16.2 ± 0.4 g (n=115). Females averaged 77.6 mm ± 1.1 (n=58, range 60-93 mm) in length and weighed 35.2 ± 2.0 g (n=41).

There was no significant difference in lengths ($F_{2,92}$=0.55, P=0.58) for male frogs across the season: October 1999 (62.3 ± 0.7 s.e. mm, n=44), November 1999 (61.2 ± 0.8 mm, n=32) and January 2000 (61.6 ± 0.8 mm, n=19). The sample sizes of females were smaller but there was no clear evidence of any differences among months ($F_{2,26}$=1.63, P=0.22): October 1999 (79.1 ± 2.5 s.e. mm, n=14), November 1999 (74.0 ± 2.6 mm, n=11) and January 2000 (72.0 ± 1.1 mm, n=4).

Discussion

Population Size Estimate

Estimates of population size based on intensive field-work are fundamental to the recovery planning for the green and golden bell frog. An earlier assessment suggested that the frog population at Port Kembla numbered 100-150 adult frogs (Goldingay and Lewis 1999). This estimate was derived from nightly counts of active frogs across multiple breeding sites. This estimate is unlikely to be accurate but should be useful in the context of population monitoring when only an index of population size is required (e.g. Lewis and Goldingay 2005).

Over 200 adult bell frogs were tagged across two years at three breeding sites at Port Kembla, including >100 in a single active season. A critical assumption in a mark-recapture study such as this is that the tags given to each captured frog provide permanent marks that allow any recaptured frog to be identified. There is a suggestion from other tagging studies of Australian frogs that some PIT tags may be lost within a short period (i.e. within days) of insertion in a frog (F. Lemckert pers. comm.). We had six field trips when at least 5 frogs were tagged on one night and at least 5 captured 1-4 days later. All captured frogs were closely examined and if they had been tagged within a 1-4 day period, a scar would have been present on the side of the body where the tag was inserted. We have no evidence of tags being lost from frogs within days of tagging. We made one observation of a tag that gave no record when scanned but the bulge of a tag can be seen through the skin so such tags were not overlooked.

Based on mark-recapture, it is estimated that the bell frog population in 1999-00 numbered 343 adult frogs across two breeding sites. Given that other breeding sites are present at Port Kembla (Steelworks, CB quarry, Boilers Point pond, residential garden ponds and one swimming pool, Korrongulla Wetland; see Goldingay and Lewis 1999), the total number of adult frogs in this area is likely to have exceeded 400 frogs in that year. There are few published estimates for the size of existing bell frog populations. Pyke and White (2001) documented seven populations (Homebush Bay, Kurnell, Broughton Island, Kooragang Island, Culburra, Meroo Lake, Crescent Head) that may contain as many as 1000 adult frogs, but the details describing how these estimates were obtained are currently unpublished. Goldingay and Newell (2005) estimated there were over 100 adult males in the Yuraygir National Park population in northern NSW. Further estimates for these and other populations are needed, with lower size estimates (around 100 or fewer) signalling that management attention should be directed at those populations because they are likely to be vulnerable to local extinction. Clearly, much further research is needed on this aspect of the population ecology of this species.

A key element to describing the size of a frog population is knowing how widely dispersed a local population might be. Anecdotal evidence suggests that bell frogs are highly vagile. Pyke and White (2001) reported a 1.5 km movement of one frog over one night in suburban Sydney. They also reported movements of up to 3 km by tagged individuals. Christy (2001) reported maximum distances moved between captures at two sites in Sydney of 632 m and 450 m. Habitat constraints are likely to have limited these distances. Goldingay and Newell (2005) recorded six tagged bell frogs moving distances of 300-500 m over vegetated sand dunes to breed in ephemeral ponds in Yuraygir National Park. At Port Kembla, one tagged female bell frog moved 1.25 km from one breeding site to another. The site of initial capture (Boilers Point) had deteriorated in quality after the frog was first tagged. There were no apparent barriers to frog migration among any of the three sites. Frogs were observed sheltering in many residential gardens in the area between Coomaditchy Lagoon and Boilers Point (unpubl. data). One resident (located approximately 400 m from the lagoon) had discontinued using an in-ground swimming pool to allow bell frogs to breed in it and this was probably a site that frogs migrated to. Indeed, an adult bell frog has been observed crossing an arterial road near the steelworks and a juvenile was observed on a road 900 m from Coomaditchy Lagoon, which was the closest known breeding site (van de Mortel and Goldingay 1998).

Surprisingly, we obtained no records of frogs moving the 500 m between Coomaditchy Lagoon and South Pond, despite a large number of frogs being tagged at both sites. The habitat between these sites was essentially similar to that which bell frogs traversed in Yuraygir National Park. Given the small distance and lack of a barrier, we have assumed that these sites are part of the same population. Furthermore, bell frogs occur at Korrongulla wetland that is located within 3 km of South Pond and likely to be linked by occasional migration and juvenile dispersal. Further study of the migration behaviour of bell frogs will be fundamental to understanding their population ecology, as well as their foraging and breeding requirements.

The structure of a population is also of considerable importance for threatened wildlife. The ratio of captured female to male bell frogs at Port Kembla was 1:2.5. There are few published data with which to put this into context. Goldingay and Newell (2005) recorded a sex ratio of 1: 7.2 for the bell frog population at Yuraygir National Park. It is not clear whether this is a real difference or whether it reflects differences in habitat use across these locations or differences in how frogs were captured. Frogs at South Pond were typically captured while perching in vegetation overhanging the breeding site, whereas at Coomaditchy Lagoon frogs were encountered around the edge of the lagoon. This was somewhat similar to that at Yuraygir National Park where frogs were captured while perching at some sites and in some months, compared to other times, when they were detected at the water level. Christy (2001) did not report the sex ratio of frogs at her two sites. Pyke and White (2001) reported unpublished observations that males predominate at breeding ponds while females are more abundant away from breeding ponds.

There are few published data on adult sex ratios of Australian frogs. Williamson and Bull (1996) found that the sex ratio for *Crinia signifera* was close to 1:1. Greer and Byrne (1995) recorded an even sex ratio among metamorphling bell frogs. However, Berven (1990) found that although the sex ratio among metamorphs of the American wood frog (*Rana sylvatica*) did not depart from parity, there was a pronounced male-biased sex ratio among adults. More research is needed on this topic for bell frogs and other Australian frogs because differences in the operational sex ratio at different locations may provide insights into different patterns of survival. Furthermore, it is the total number of females present in a population that will determine its viability.

Male bell frogs at Port Kembla were similar in length to those at Yuraygir National Park. However, females averaged about 5 mm longer at Port Kembla. This was also evident in the largest frogs measured; 83 mm at Yuraygir but 93 mm at Port Kembla. There was no evidence for a change in the length of male or female frogs at Port Kembla over a 4-month period in 1999/00. However, few frogs were recaptured during this period to enable a comparison of individual growth rates. When such a comparison was conducted for male frogs at Yuraygir, no difference was found. Further study of growth rates in the field will be important because it will provide insights into longevity and possibly site productivity.

At Port Kembla, 85% of frogs were uniformly green or predominantly green with minor amounts of brown spots and blotches. This compares dramatically to frogs at Yuraygir National Park where only 19% of frogs were uniformly green or green with large amounts of brown (Goldingay and Newell 2005). This reveals morphological differences among some populations that are worthy of further investigation. The exact significance of this variation is unknown. Such variation in colouration may be of considerable interest in understanding patterns of spectral reflectance among bell frog populations and interpreting its ecological significance (see Buttemer *et al.* 1996).

Only 13 of 244 individuals tagged during this study were recaptured outside the season in which they were first tagged. The greatest interval was for one male and two females that were recaptured 14-16 months after initial capture. The lack of recaptures across years compared to within years suggests that most adult frogs survive for only about two years. Similar findings were reported for Yuraygir National Park (Goldingay and Newell 2005). A high rate of recapture in one season at Yuraygir when more surveys were conducted suggests that these patterns are not caused by tag-induced mortality. Further study of patterns of longevity is required because this will influence our understanding of the viability of populations of bell frogs. Shorter-lived populations (i.e. where predation rates are greater) will be more susceptible to population decline under adverse environmental conditions.

Conservation and Management of Bell Frogs at Port Kembla

This study has established that the number of adult frogs across the various breeding sites in Port Kembla is likely to exceed 400 individuals. This estimate begs the question: is this a viable population? At this stage this is impossible to know without conducting a population viability analysis. However, many of the life history parameters that are needed to conduct such an assessment are too poorly known. The next best approach is to conduct long-term monitoring. How might this be conducted? The sort of monitoring described by Goldingay and Lewis (1999) would be appropriate to provide a general approximation of the level of the population size at some key sites like Coomaditchy Lagoon. Two counts each October-December and January-February may be sufficient. The latter has been useful for scoring the number of juvenile frogs as an index of breeding success. This monitoring could be complemented every 2-3 years by an intensive tagging project conducted over several months that aims to provide a simple estimate of population size for a given year. If conducted over a sufficient period of time these studies should provide some assessment of population stability.

It is not appropriate to assume that the size of the adult bell frog population at Port Kembla is sufficient to preclude the need for management action. Although successful breeding does occur at Coomaditchy Lagoon, the presence of mosquito fish almost certainly limits current breeding intensity (see Goldingay and Lewis 1999). The construction of ephemeral ponds to improve breeding

would increase the adult population size at Port Kembla and provide better insurance against stochastic effects on individual breeding sites. On-going monitoring would also be needed to determine the influence of any management actions on the population. Such habitat restoration and long-term monitoring will provide the best chance of ensuring the conservation of this green and golden bell frog population.

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